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APPLICATION OF A HYBRID SYSTEM FOR EARLY DETECTION OF FOREST FIRE

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ABSTRACT

If water is the bloodstream of life, air - lungs, soil - food, then forests are undoubtedly life. Forests play a key role in the quality of life on earth as they make up the bulk of renewable natural resources, as well as providing ecosystem goods and services. Forests serve as the primary source of many non-timber and timber products and play an important role in sustaining human life on earth by maintaining adequate environmental conditions. Forest fires occur i.e., manifest in forests and on forest land. From all causes of forest damage, of abiotic nature (extreme temperatures - droughts and frosts, snow, hail, wind, torrential rains, acid rain, etc.) and biotic nature (humans, insects, fungi, bacteria, viruses, etc.), forest fires are the greatest threat for forests and natural ecosystems as a whole. Aided by the wind, they spread with great speed, especially in the coniferous forests and in a very short time leave desolation behind. The subject of the research are the different types of systems for early detection of forest fires, according to the applied technical solutions in other countries, the configuration of the land in the Republic of North Macedonia and the comparative analysis of different systems, we consider the most appropriate to use a hybrid system consisted of video camera networks and wireless sensor networks that would complement video surveillance of those parts of the forest that are not in the field of view of the cameras. Implementing this or a similar model in the Republic of North Macedonia would have multiple benefits in order to reduce the consequences of forest fires, illegal logging, pollution, etc.

Keywords: *fire, sensors, cameras, risk, danger*

1. INTRODUCTION

Forests play a vital role in the maintenance of the ecological balance of the Earth. Sadly, forest fires are getting detected only when they spread on a big surface, which makes controlling and putting them out very difficult, and in a lot of cases it is almost impossible. Forest fires are a universal problem and destroy big areas in all countries. These fires destroy many natural resources, as well as the live world and their natural habitat, they produce basic disorder of the ecosystems and pollute the environment. All of this results into an irreparable harm on the atmosphere and environment, where 30% of the CO_2 emitted in the atmosphere comes from the forest fires (Ahmad, & Alkhatib, 2014). Besides that, they destroy thousands of acres while they cause tragic loss of people's lives, houses, property, flora and fauna. In the long run, forest fires are a big threat to the ecological development of the forests and protection of the environment, change of local time, global warming and extinction of rare species of the flora and fauna.

2. FIRE TRIANGLE

All fires are a result of a physical and chemical process which happens when essential elements like fuel, heat and oxygen are all in the needed combination to support the process of combustion of the fuel material. If the conditions of oxygen temperature, humidity and fuel material are in the joint, there will be conditions for a fire to happen. Analyzing these three elements, Osborn concluded that all three elements have equal meaning for the process of burning, i.e., in case of missing one element, there will not be a process of burning, because the conditions for a fire are lost. The combination of these three elements is called a "Fire Triangle" (Figure 1).

The fuel is critical in both triangles: fuel, oxygen and heat of the fire triangle, and fuel, topography and time of the fire ecological triangle. Fuel does not cause fire, but it can change the character of the fire; it provides easy ignition and affects the size and intensity of the fire. The fuel is a vegetative material that burns in the forest fire.

In the forests, there is a lot of fuel material and oxygen that are always present. To complete the fire triangle, the only thing that is needed is enough heat or a source of ignition to start the initial burning, and after that there is a need of heat that will support and expand the burning.

If one of these three elements can be eliminated, the fire can be put out. The basic flammable component in the forest fire is carbon. The reaction is expressed simply through the relation:

$C+O_2=CO_2+\text{heat energy}$

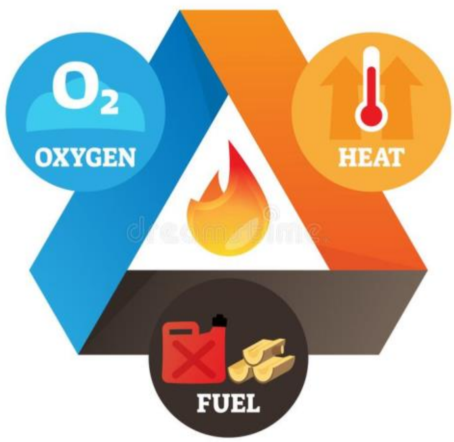

Figure 1. Fire triangle

The three elements of the fire triangle are:

Oxygen. Oxygen as a free gas is represented in the atmosphere with almost 20,95% by volume. Just like that, it is represented in the nature and related to other elements in another way (in water, in vegetations and many other substances). In the process of combustion, the oxygen necessary for oxidation is provided in sufficient quantities from the surrounding oxygen. When the content of the oxygen gets below 15% in the zone of burning, the fire that burned freely will cross to smoldering. When the contents of the oxygen in the atmosphere will fall below 8%, the fire that was smoldering will stop burning and the fire will be put out (Bryan, & John, 1982). The oxygen can also be provided from other sources that release molecules of oxygen during their chemical reaction. This means that we need to be careful with these oxidizers, they have to be at the place of the fire and divided from the fueling material if it is possible. On the other hand, lowering the oxygen can be done with suffocation or covering – most often with sand in case of a forest fire, or it can be done with mills, bags, branches, etc.

Fueling Material. Forest fires are firstly controlled with working along the fuel from the fire triangle. This is done with limiting the fire in a defined surface with fuel with the help of a fire line and natural barriers if they are available. With the maintenance of the fire in the limits of the line, we can say that the fire is limited and under control. This line is most often made with removing the surface fuel with tools or equipment for exposing the mineral water of the fire or with watering by the line's length.

Heat source. To start a fire, the fuel must be brought to a temperature of ignition. If the temperature drops below the point of ignition, the fire goes out. Water is the most effective agent for lowering the heat. The usage of sand is also a good way of lowering the heat.

The heat source is an important part in the fire development. It can be of an anthropogenic or natural origin. Also, two types of heat are needed for fire occurrence, the first one is to start the initial burning, and the other one is to maintain and expand the fire. In the initial phase, the heat source (cigarette), it heats up the fueling material to a temperature of 100-200°C. At that temperature, the water is evaporating and there is an occurrence of gases (methane, ethylene, acetylene). In the presence of oxygen from the air at a temperature of 230-250°C there is ignition of the gases, occurrence of flame and the process of heating up is starting, and at a temperature of 300-400°C it converts into a flaming fire. After that the temperature is around 400-600°C, the tree is burning, it decomposes and carbonizes, the carbon continues to burn without any flame, and the temperature can be as high as 1000°C. The final result is ash (Веселиновић & Миленковић, 2007). In the second phase, the heat used for heating, evaporating and drying of the surrounding material provides material that burns and the heat is spreading around increasing the temperature to a point of ignition. The heat is spreading with radiation, conduction and convention (the heat is rising to the upper layers which are cold and heats them up).

Because of the massive exposure to direct sunlight and the biochemical reaction in the fueling material, there can be self-ignition. This happens rarely as a way of creating heat for forest fire.

The forest fire is a dynamic phenomenon that changes its behavior as time goes by. The fire expands through the fuel. A complex transfer of heat and thermo-chemical process that define the fire behavior is done (Scot, 2012).

3. FOREST FIRE DETECTION SYSTEMS

The importance of the early detecting of fires is best illustrated in the example of (Ahmad & Alkhatib, 2014) that states that for putting out a fire after one minute, only one glass of water is enough, after two minutes of burning you will need 10 liters of water, and after 10 minutes of burning you will need 1000 liters of water.

According to the analyzed literature, there are systems that can discover forest fire from land or airspace. The detecting of the forest fires from land can be done from fixed points (some dominant elevations or observers) by trained persons with or without optical equipment (binoculars) or it can be done while employees of the forestry sector are moving during their usual activities (Vasić, 1992). During the fire season, a 24 hour watch is organized. As other systems lean on the human factor, this way did not give satisfactory results in the fire detection, but there are conflicting opinions about this as well. The usage of automatic fire detection systems gave much better results.

3.1. Airplanes, UAVs and satellites

Airplanes are one of the oldest aerospace early fire detection systems that is based on planned watch while using small aircrafts that belong to the farming aviation, also known as air patrols in the fire season. Their usage in the fight against the forest fires started in the 1920s, they were putting out forest fires with the usage of water dispensing (Jendsch, 2008). Their success in putting out fires was not very good, because the airplanes were used for fire detecting instead of fire extinguishing. After the Second World War, in the late 60s fire extinguishing airplanes and helicopters were in the process of improvement (Jendsch, 2008). This method of fire extinguishing is marked as a very expensive and very risky way because of how close to the fire pilots must fly. The annual number of airplane crashes connected to fire extinguishing caused public concern about the pilot's safety.

The improvement of UAVs created an opportunity for airplane fire extinguishing because they will substitute the pilots. In the last few years, different kind of UAVS were the answer to the success of the early fire detection. (Yuan, Zhang & Liu, 2015). An example for that is a sophisticated drone made by Krull and his co-workers (Krüll, et al, 2012), there is another project used for forest fire detection and forest fire prediction in the Balkan-Mediterranean territory as it is shown in Figure 2 (Moulianitis, Thanellas, Xanthopoulos, & Aspragathos, 2019). The basic configuration of this system is that it uses a network full of cameras that provide a stable supervision of the forest region. However, the challenges in this implementation are the places (space) that these cameras need to be placed in, just so they can cover national parks and forest reserves. Also, the systems that are based on cameras give a lot of fake positive signals. For these problems to be solved, UAVs with more rotors are being used to examine the signals that the cameras transmit. The fake signal problems as well as efficiently using the limited time of flying are solved with these kinds of UAVs.

A more comprehensive configuration includes usage of fixed wing and rotational wing UAVs, they provide careful following of the hard terrain that cannot be covered with cameras. Fixed wing UAVs with high endurance can fly almost 8 to 10 hours and are equipped with infrared cameras that can provide long term supervision of the region (figure 2). As soon as the temperature level of the cameras increase, the GPS signals are being sent to the control station. The drone will continue to patrol around the region. When the signals are sent and delivered, two smaller UAVs with rotational wings will be used to watch the region closer just to make sure if the signal is real or fake. The further improvement uses watch data, and that data is used for the artificial intelligence opportunities to be researched that will later be used for future improvement of the drone forest fire systems.

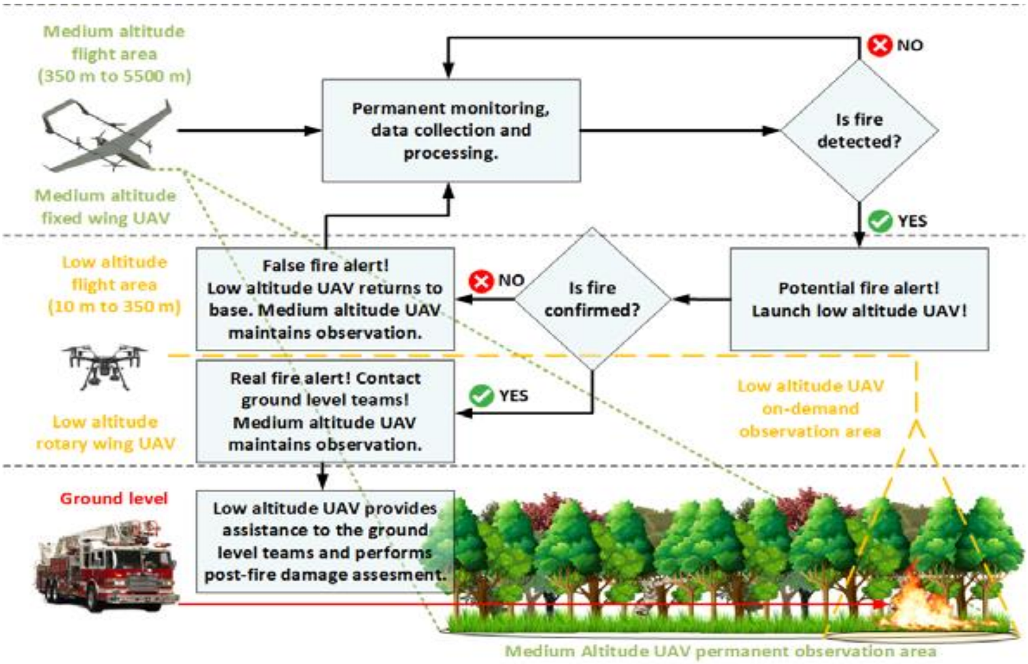

Figure 2. Network of unmanned aerial vehicles wildfire (Source: SFEDA Forest Monitoring System for Early Fire Detection and Assessment in the Balkan-Med Area)

UAVs or drones find a bigger usage in risk watching. They can be used for data collection that can define risk of fire, but they are also used for early fire detection and supervising the fires that already burn (Merino, Caballero, Martinez-de-Dios, J.R. et al. 2012). UAVs can be equipped with different kinds of sensors. They can be used for registering the temperature change of the surface that they flyover, they use sensors that react on infrared space of the spectrum. We can later divide them into sensors that react to long and medium waves with length of 3-5 µm, that are typical for forest fires. The other group are sensors that register flame with wavelength of 3 µm.

The European Forest Fire Information System (EFFIS) has an “Active Fire Detection” module that is used for detecting new fires based on a thermal anomaly. A computer algorithm is comparing the temperature of the potential fire with the temperature of everything around it. If that difference is defined beforehand, then that place is announced as an active fire. This layer is used from NASA’s platform called FIRMS which means Fire Information for Resource Management System.

Fire information is collected with the help of MODIS (Moderate Resolution Imaging Spectroradiometer) which is found in TERRA (EOS AM-1) and ACQUA (EOS PM-1) satellites. TERRA is orbiting around the Earth in the north direction and crosses over the equator in the early mornings, while ACQUA is orbiting in the opposite direction and crosses over the equator at noon. These satellites are recording the whole surface of the Earth, their time resolution is one to two times daily, while their spatial resolution is one kilometer. The difference in the temperature between the surface of the fire and its surrounding that does not burn at all allows mapping of the active fires.

The second module that EFFIS uses from FIRMS is VIIRS (Visible Infrared Imaging Radiomer Suite) that uses similar algorithm as the one MODIS uses but it has a spatial resolution of 375 meters. VIIRS is integral part of NASA/NOAA Suomi National Polar-orbiting Partnership (SNPP).

The information obtained with the sensors is refreshed about 6 times daily at the EFFIS portal, after two to three hours from the MODIS/VIIRS recording collection and processing. The accuracy of the place of active fire depends on the sensor's spatial resolution, so, small fires or fires that are hidden behind clouds or smog stay unregistered. On the other side, the satellites register other sources of heat that are not even connected to the fires. Beside the place for every verified fire, the system gives information about the vegetation type that is caught in the fire, the geographical coordinates and administrative data for the country or region. To eliminate a false alarm, the FIRMS system uses algorithms that consider the vegetation type, that is the category of the surface that is surrounding the potential fire, then the distance to the settlements and artificial surfaces is used as a basis to define the level of every fire that is displayed at the EFFIS portal.

Macedonian Forest Fire Information System (MKFFIS) uses recordings from the MSG Seviri satellite (channel from 3900 to 10800nm) with spatial resolution of 3x3 kilometers and time resolution of 15 minutes, it also uses recordings from the Terra/Aqua-MODIS satellite (channel from 3900 to 10800nm) with spatial resolution of 1x1 kilometer and time resolution of 12 hours. The combination of the data from these two satellites is a way of trying to make up for the cons from the low spatial resolution that the MSG Seviri recordings have and the low time resolution that Terra/Aqua-MODIS has.

The minimal surface that can be covered is 1 acre, which in the available literature is stated as a big fire for whose extinguishing around 30 people will be needed, these kinds of problems are one of the biggest cons of the early fire detecting systems.

3.2. Optic systems and video cameras

The automated early fire detection system from land is using different types of sensors (Table 1).

The usage of rotating video cameras is the longest method yet, they can be connected to a system for automatic detection and positioning the fire (Fernández-Berni, Carmona-Galán, & Carranza-Gonzalez, 2008). The system functions in a way that the camera is recording the surface in front of it in correct time frames, while it determines the azimuth and the time of the recording which is saved on a hard disk up to 200 days. The advanced systems have software that is used for automatic visual fire detection. When the software detects fire from one camera connected to a system, it checks the information with the other cameras just so it prevents false alarms. If there is at least one more camera that detected the same fire, it is possible from the angle of the camera to even detect the precise location of the fire.

Table 1: Different types of fire detection sensors from land

Video Camera	IR Camera	IR Spectrum meters	LIDAR system
✓ Sensitive to the part of the spectrum that can be seen with naked eye ✓ Smoke detection throughout the day ✓ Flame throughout the night	✓ Registers heat that is released from the burning	✓ Determines spectral characteristic s of the smoke	✓ Detects smoke and distance ✓ Uses laser technology

One of the most popular fire detection systems is the German type called Firewatch (http://www.fire-watch.de/). The system (figure 3) is used in 11 countries, with 303 sensors the system covers a forest of 5695000ha. The system uses optical sensors that perform a full rotation from 360° in a time frame from 4 to 10 minutes and it moves with steps of 10°. The collected data from the sensors that are mounted on towers, that must be 10 meters above the forest, and with the help of a wireless network the data gets transferred to a central computer. In good weather, the system detects smoke at 60 kilometers distance, and it can cover a surface of 70000 acres. The sensors detect the direction of the smoke and the distance on which it is located.

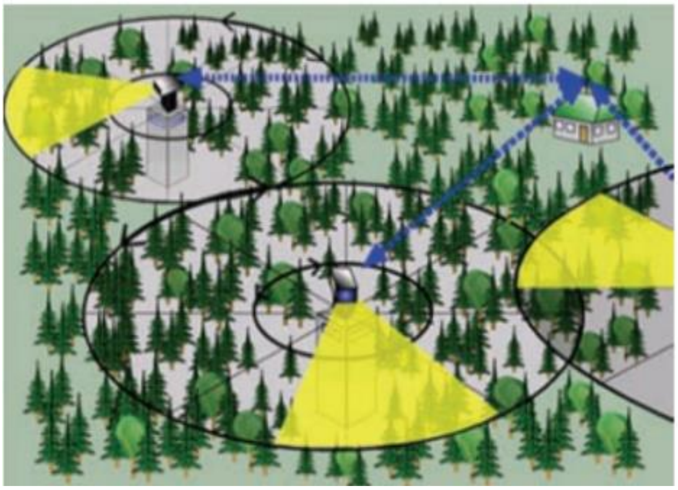

Figure 3. FireWatch system. (Source: FireWatch, „An Early Warning System for Forest Fires, successfully in the global use," 2013, retrieved from http://www.fire-watch.de/systemoverview).

ForestFireFinder (http://www.nqns-is.com), figure 4, with the help of an optical spectrum meter, the size of the sunlight and the way that the atmosphere absorbs it, can be analyzed. As the absorption depends on the chemical composition of the atmosphere and is changed by the smoke, the system can detect different types of smoke, from smoke which occurred from the burning of the vegetation to industrial smoke. The system detects smoke at a distance of 15 kilometers, and depending on the analysis of the smoke, the system decides if it is needed to sound an alarm and send information to the control center.

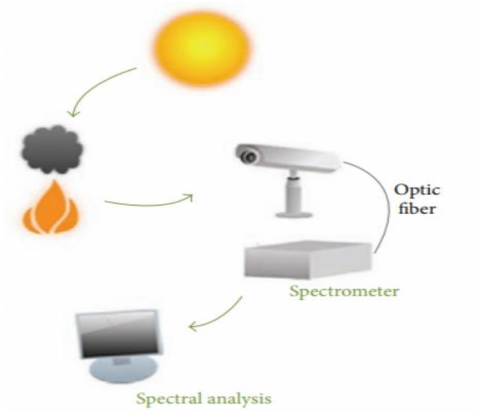

Figure 4. ForestFireFinder system for early detecton of forest fire. (Source: Retrieved from NGNS Forest Fire Finder2013, http://www.ngns-is.com/eng/FFF_eng.html).

ForestWatch (http://evsusa.biz/productsservices/forestwatch/), figure 5, is one of the best automatic fire detection systems in the world. It has cameras, image collecting computers, communication programs that analyze the collected data. The system is working by itself for 7 days a week, 24 hours a day because it has a camera with 0,005 lux sensitivity. The camera can rotate for 360 degrees and it can vertically move from +33^o to -83^o. The collected data from the observing stations are sent to the central computer where they are analyzed and with the help of advanced software, one of the three ways of warning is defined:

1. New fire;
2. Old fire that is still active, and
3. Undefined state, that needs help from the operator on duty.

The system works with the help of a digital model of the terrain, so the software is registering the position automatically and sends the exact GPS coordinates. The system can send data to the fire departments automatically.

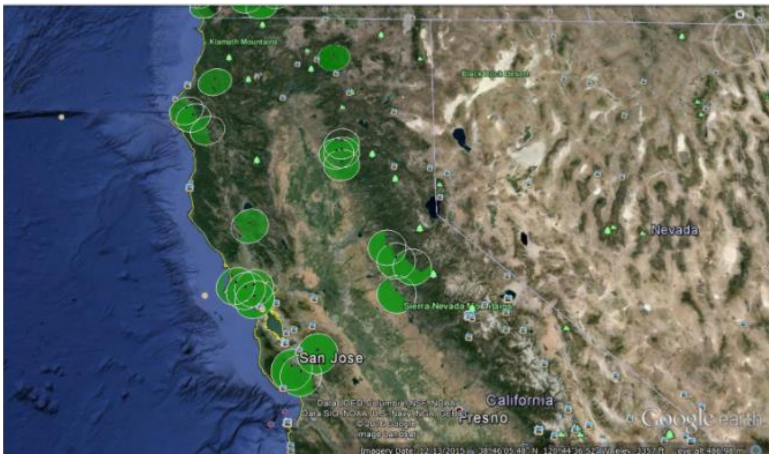

Figure 5. Network of installed ForestWatch systems in North California

(Source: Retrieved from http://evsusa.biz/productsservices/forestwatch/)

The main problem of all visual fire detection systems is the big numbers of false alarms that occur because of the bad weather conditions, like cloudiness, rain, dust or human activities. For this reason, these systems require engaging of a person who will watch over these systems while the fire season lasts.

3.3. Wireless sensor networks - WSN used for fire detection

In the last couple of years people research the opportunity of using the wireless sensor networks to communicate with the central unit wirelessly. These devices are made of sensors, microprocessors and wireless transmitters and they all use the same battery as a power unit. The sensors can register different physical parameters like temperature, relative humidity, air pressure, and they can even register chemical parameters like the amount of carbon monoxide, carbon dioxide and nitrogen dioxide. A lot of protocols and computer algorithms are created just so they can manage the networks (Bouabdellah, Noureddine, & Larbi, 2013) and they all need to save as much power as they can because they do not have the opportunity to add another power source in the forests, but scientists are developing systems that can function up to 16 years using only one Ah lithium battery (Lazarescu, 2015). Parts of the network only work periodically when they need to send information and the reason for that is to save as much power as they can, then it automatically sends information if it detects smoke (Yu, Wang, & Meng, 2005). The devices are placed around 100 meters to 1 kilometer away from each other. The information that the sensors collect can be used for early fire detection and even for predicting if there will be fire, these kinds of systems work with the FWI index (Hefeeda & Bagheri, 2007). On the other hand, (Hartung, Han, Seielstad & Holbrook, 2006), proposes a hybrid system (FireWxNet) that upgrades the wireless sensor network with web cameras that turn on only when needed and are used to check and verify that there is an actual fire. As to the example of wireless network devices “Forest Wizard”, this network detects fire at 800 meters and its biosensor is made from DNA extraction of Melanophila acuminate from the Buprestidae family, a species that lives in burned trees. These devices have self-powering unit with micro solar panels, and a chip that converts the kinetic energy of the vibrations of the surface into electric energy. Besides the fire detection, these kinds of systems give information about the fire intensity and the direction of spreading.

CONCLUSION

There are a lot of forest fire detecting techniques but, in this thesis, we focused on the optical systems and digital cameras, systems based on satellites, airplanes and UAVs, as well as wireless networks. We emphasized the pros and cons of every single system. After comparing these systems, we focused more on the wireless networks as the best technique for early fire detection. They have the following features:

- ✓ They can provide all required information that influences the environment at any moment accurately;
- ✓ They can cover any area size, plus its scalable network;
- ✓ They can observe and influence the physical world around them;
- ✓ They can be connected to many devices and add many kinds of sensors to measure various parameters;

- ✓ There is no need to build towers or set up complicated communication links;
- ✓ They can be deployed anywhere even in inaccessible places.

All the wireless network systems have sensors that give information about the fire occurrence in the initial phase of the process. Besides, they make early detection, information about the fire, they can even predict danger. The price of these devices with this kind of advanced technology is getting lower each day, and with the improvement of the sensors, we will not need as many sensors per unit area and the price will be even lower. In our conditions, this kind of systems can be used for early fire detection in crucial objects that are not in the visible field of the cameras because of how big the terrain and its form is.

With everything that we said, for early forest fire development it is best to use a hybrid system which contains networks with video cameras and wireless networks with sensors that will help the video overwatch that is not covered with the cameras.

REFERENCES

1. Ahmad AA, Alkhatib A. (2014). *Review on forest ire detection techniques*. International Journal
of Distributed Sensor Networks.

2. Bouabdellah, K., Noureddine, H., & Larbi, S., (2013). Using Wileless Sensor Networks for Reliable Forest Fires Detection. Procedia Comput. Sci., 19, 794-801.

3. Bryan, John L. (1982). Fire Suppression and Extinguishing Systems. New York: Macmillan Publishing Co.

4. Vasić, M. (1992). Šumski požari, Šumarski fakultet. Univeryiteta u Beogradu.p 105. Beograd..

5. Веселиновић, М., Миленковић, С. (2007). Превенција шумских пожара приручник за едукацију тренера. Београд: Институт за шумарство. пп. 1-104.

6. Fernández-Berni J, Carmona-Galán R& Carranza-Gonzalez L (2008). A vision-based monitoring system for very early automatic detection of forest fires. In First International Conference on Modelling, Monitoring and Management of Forest Fires, 17-19 September 2008, Toledo, Spain. (Eds J de las Heras, CA Brebbia, D Viegas, V Leone) pp. 161-170. (WITPress: Southampton, UK).

7. ForestFireFinder system for early detecton of forest fire, Retrieved from NGNS Forest Fire Finder2013, http://www.ngns-is.com/eng/FFF_eng.html

8. FireWatch, „An Early Warning System for Forest Fires, successfully in the global use," 2013, retrieved from http://www.fire-watch.de/systemoverview).

9. Hartung C., Han R., Seielstad S., & Holbrook S., (2006). FireWxNet. A multi-tiered portable wireless system for monitoring wether conditions in wildland fire environments, in Proceedings of the 4th International Conference on Mobile Systems, Applications and Services (MobiSys '06), pp. 28-41, ACM, Uppsala, Swedan.

10. Hefeeda, M. & Bagheri, M. (2007). Wireless Sensor Networks for Early Detection of Forest Fires 2007 IEEE International Conference on Mobile Adhoc and Sensor Systems, 2007, pp. 1-6, doi: 10.1109/MOBHOC.2007.4428702.

11. Krüll W, Tobera R, Willms I, Essen H & von Wahl N. (2012). Early Forest Fire Detection and Verification using Optical Smoke, Gas and Microwave Sensors Procedia Eng. 45 584–94.

12. Lazarescu, M. (2015). Design and Field Test of a WSN Platform Prototype for Long-Term Environmental Monitoring Sensors, 15, 9481.
13. Merino, L., Caballero, F., Martinez-de-Dios, J.R. et al. (2012). An Unmanned Aircraft System for Automatic Forest Fire Monitoring and Measurement, Journal of Intelligent& Robotic Systems 65: 533-548.
14. Moulianitis V C, Thanellas G, Xanthopoulos N and Aspragathos N A. (2019). Evaluation of UAV Based Schemes for Forest Fire Monitoring (Springer, Cham) pp 143–50.
15. Network of installed ForestWatch systems in North California, Retrieved from http://evsusa.biz/productsservices/forestwatch/
16. NGNS Forest Fire Finder2013, Retrieved from http://www.ngns-is.com/eng/FFF_eng.html
17. Prescott, N. A. (2006). „An Inconvenient Truth“ directed by Davis Guggenheim.
18. Scot JH. (2012). Introduction to Wildire Behaviour Modeling. National Interagency Fuels, Fire, &Vegetation Technology Transfer, Wild Fire Management RD&A; 2012.).
19. SFEDA Forest Monitoring System for Early Fire Detection and Assessment in the Balkan-Med Area
20. Yu, L. Y., Wang, N., Meng, X. Q. (2005). Real-time forest fire detection with wireless sensor networks. International Conference on Wireless Communications, Networking and Mobile Computing Proceedings, Wuhan, China. 1-2, pp. 1214-121.
21. Yuan C, Zhang Y & Liu Z. (2015). A survey on technologies for automatic forest fire monitoring, detection, and fighting using unmanned aerial vehicles and remote sensing techniques Can. J. For. Res. 45 783–92.